



Speed Control & Parameter Monitoring of Single-Phase Induction Motor Using IoT

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Abstract: This paper presents an innovative approach to speed control of an induction motor using zero-cross detection and TRIAC logic, integrated with an IoT-based monitoring system. The objective is to optimize motor efficiency, minimize power consumption, and enable remote monitoring. A prototype system was developed using ESP32, voltage and current sensors, and an IoT dashboard (Blynk) for real-time data visualization and control. Experimental results demonstrate the effectiveness of the proposed method in regulating motor speed and enhancing energy efficiency. The findings contribute to the advancement of smart industrial automation.

Keywords - Induction Motor, IoT-Based Monitoring, Vector Control Algorithm, Zero Cross Detection, TRIAC Logic, Predictive Maintenance, Industrial Automation.

I. INTRODUCTION

Induction motors are one of the most widely used electrical machines in industrial applications due to their robustness, low maintenance requirements, and high efficiency. They play a critical role in various sectors, including manufacturing, HVAC systems, and automation processes. However, traditional methods of speed control, such as variable frequency drives (VFDs) and pulse-width modulation (PWM)-based controllers, often require sophisticated circuitry, expensive components, and may introduce harmonic distortions in the power system. These complexities lead to increased energy losses and operational costs, making them less suitable for cost-sensitive applications. To address these challenges, this study presents an alternative approach for speed control of an induction motor using zero-cross detection and TRIAC-based phase-angle control. By leveraging zero-cross detection, the system precisely identifies the points where the AC waveform crosses the zero-voltage level, ensuring accurate triggering of the TRIAC. This phase-angle control mechanism regulates the power delivered to the motor, thereby modulating its speed efficiently without the need for complex controllers. Furthermore, with the rapid advancements on the Internet of Things (IoT), real-time monitoring and control of industrial equipment have become more feasible and accessible. Integrating IoT technology into motor speed control systems enables continuous data collection, remote supervision, and predictive maintenance. In this study, an ESP32 microcontroller is used as the central processing unit to facilitate data acquisition and communication with an IoT platform. The system employs voltage and current sensors to monitor power consumption, while the collected data is visualized on an IoT dashboard (Blynk), providing users with real-time insights and control over motor operation. The key objectives of this research are:

- To develop an energy-efficient and cost-effective induction motor speed control system using zero-cross detection and TRIAC logic.
- To integrate IoT-based monitoring for real-time data visualization and predictive maintenance.
- To evaluate the performance of the proposed system in terms of energy efficiency, speed regulation, and operational reliability under various load conditions.

II. LITERATURE REVIEW

IoT-Based Remote Monitoring and Control of Industrial Motors: Silva et al. (2022) explored an IoT-based remote monitoring system for industrial motors, focusing on real-time data acquisition and predictive maintenance. Their system integrated wireless sensors and cloud computing to track motor performance and detect faults before failure. A major contribution of this work was its adaptive control mechanism, which dynamically adjusted motor speed based on operational demands. However, the study noted latency challenges in wireless communication, which could affect real-time responsiveness. [1]

Challenges and solutions in IoT-Based control systems for induction motors: Nguyen et al. (2023) analyzed the key challenges in IoT-driven induction motor control, particularly in cybersecurity, latency, and real-time decision-making. Their study proposed an edge computing approach to reduce dependency on cloud servers, thereby minimizing communication delays. Additionally, the paper discussed AI-based anomaly detection, which improved fault diagnosis accuracy. One of the limitations highlighted was the energy consumption of IoT nodes, which required further optimization. [2]

Real-Time IoT-Based Control and Monitoring System for Induction Motors Using Raspberry Pi: Ghofrani and Shafei (2020) designed a real-time IoT system using Raspberry Pi for controlling and monitoring induction motors. Their architecture utilized MQTT protocols for data transmission and implemented remote speed control via mobile applications. The study demonstrated the effectiveness of low-cost embedded systems in industrial automation. However, they identified scalability concerns, as Raspberry Pi had limitations in handling multiple motors simultaneously. [3]

IoT-Based predictive maintenance for induction motors using machine learning algorithms: Singh and Reddy (2020) developed an AI-powered predictive maintenance model for induction motors. Their system used machine learning algorithms (SVM, ANN, and Random Forest) to predict motor failures based on vibration, temperature, and power consumption data. The results showed a significant improvement in fault detection accuracy, with an 85% reduction in unplanned downtime. The research highlighted the need for continuous training of AI models, as new fault patterns could emerge over time. [4]

Speed control of induction drive by temperature and light sensors via PIC: Barsoum (2010) proposed an induction motor speed control technique using temperature and light sensors interfaced with a PIC microcontroller. The study demonstrated a simple and cost-effective approach for speed regulation based on environmental conditions. However, the system lacked real-time IoT connectivity, making remote monitoring infeasible. [5]

III. METHODOLOGY

The proposed system consists of an ESP32 microcontroller, zero-cross detector, TRIAC module, voltage and current sensors, and an IoT-based user interface. The control logic involves detecting zero-cross points in the AC signal and triggering the TRIAC at specific phase angles to regulate power delivered to the motor.

3.1 Hardware Implementation

- **ESP32 Microcontroller:** Manages data processing and communication with the IoT platform.
- **Zero-Cross Detector:** Identifies the zero-crossing points in the AC waveform for precise TRIAC triggering.
- **TRIAC Module:** Controls the power supplied to the motor by phase angle modulation.
- **Voltage & Current Sensors:** Monitor power consumption and send real-time data to the IoT dashboard.

3.2 Software Implementation

The firmware is developed in Arduino IDE, using Blynk for IoT visualization. The motor speed is controlled via a slider in the Blynk app, which adjusts the TRIAC triggering angle accordingly. Realtime data logging enables predictive maintenance and anomaly detection

IV. TRADITIONAL MOTOR SPEED CONTROL TECHNIQUES

Several conventional methods exist for controlling the speed of induction motors, including:

4.1 Voltage-Frequency (V/f) Control:

- In this method, the ratio of voltage to frequency is maintained constant to ensure efficient torque production.
- It is widely used in Variable Frequency Drives (VFDs) and provides smooth speed control.
- However, VFDs are expensive and introduce harmonic distortions, affecting power quality.

4.2 Pulse-Width Modulation (PWM) Control:

- PWM techniques regulate motor speed by adjusting the duty cycle of the input voltage signal.
- These methods offer precise speed control and high efficiency but require complex power electronics.
- The major drawback is the generation of harmonics, which can lead to overheating and motor insulation degradation.

4.3 Rotor Resistance Control:

- Applicable primarily to wound rotor induction motors, this method involves adding external resistance to the rotor circuit.
- While it offers good speed regulation, it results in significant energy loss due to resistive dissipation.

4.4 Stator Voltage Control:

- This method controls motor speed by varying the stator voltage, typically using a thyristor-based controller.
- It is a simple and cost-effective technique but leads to poor torque characteristics at low speeds.

Each of these methods has its own set of challenges, including high power losses, increased system complexity, and high costs, making them less suitable for cost-sensitive and energy-efficient applications.

V. PROPOSED MOTOR SPEED CONTROL TECHNIQUES

5.1 TRIAC-Based Phase Angle Control: Phase-angle control using TRIAC is an alternative method for induction motor speed control that offers a simpler and more cost-effective solution.

- A TRIAC (Triode for Alternating Current) is a semiconductor device that allows bidirectional current flow when triggered.

- The firing angle of the TRIAC determines the amount of power delivered to the motor, enabling precise speed control.
- This method avoids complex power electronics, making it an attractive alternative for low-power applications.

Studies have shown that phase-angle control can significantly reduce energy consumption when properly implemented. However, ensuring smooth operation and minimizing power fluctuations remain key challenges.

5.2 Zero-Cross Detection for Improved Performance: Zero-cross detection (ZCD) is a technique used to identify the points where an AC waveform crosses zero voltage. This enables precise triggering of the TRIAC, ensuring smooth power delivery to the motor.

Advantages of Zero-Cross Detection:

- Minimizes electrical noise and reduces switching losses.
- Enhances the efficiency of TRIAC triggering, leading to better motor performance.
- Reduces unwanted harmonics and improves overall power quality.

Several studies have demonstrated that combining zero-cross detection with phase-angle control results in a more efficient and stable motor control system.

VI. EXPERIMENTAL SET-UP

The proposed system consists of the following key components:

- **ESP32 Microcontroller:** Handles data processing, TRIAC triggering, and IoT communication.
- **Zero-Cross Detector:** Identifies the zero-voltage points of the AC waveform to ensure precise TRIAC firing.
- **TRIAC Module:** Controls the power supplied to the motor by adjusting the phase angle of the AC signal.
- **Voltage & Current Sensors:** Measure real-time power consumption for performance analysis.
- **IoT Platform (Blynk):** Provides a user interface for remote monitoring and speed control.

The overall architecture is illustrated in **Figure 1** (circuit diagram can be included in the final paper).

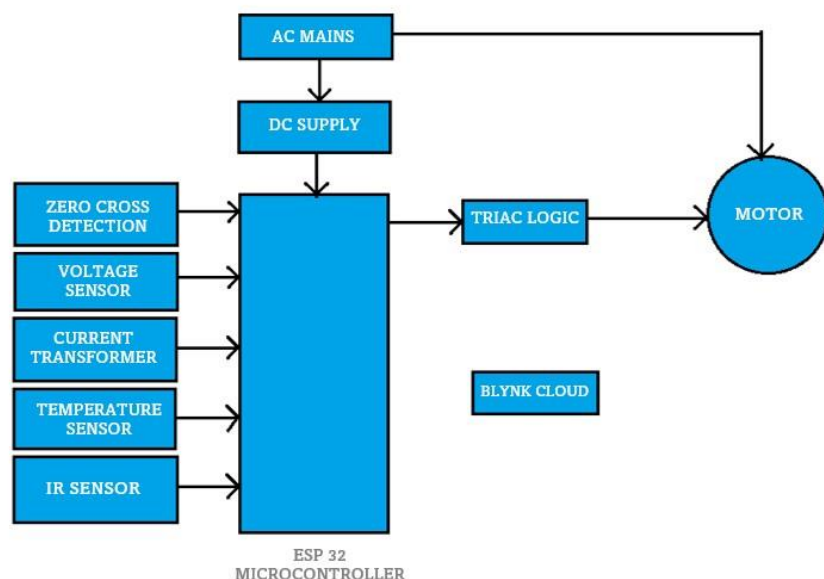


Figure 1: Block diagram of proposed system.

VII. CONCLUSION

This research successfully demonstrates a cost-effective and efficient method for controlling the speed of an induction motor using zero-cross detection and TRIAC-based phase-angle control, integrated with an IoT-based monitoring system. The proposed system enables precise speed regulation, energy savings, and remote monitoring, making it a viable solution for industrial automation and smart energy management

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